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Research paper

Development of an unmanned surface vehicle for autonomous navigation in a paddy field

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ABSTRACT

The objective of this research was to develop an unmanned surface vehicle (USV) using global positioning system (GPS) compass for autonomous navigation in a paddy field. The surface vehicle used in the research was a radio-controlled air propeller vessel modified into an unmanned surface vehicle platform. The GPS compass was attached to the top of the USV platform as the navigation sensor to provide the position and heading angle. The USV platform can navigate automatically on predefined pathways. From the trajectory data of line-following navigation measured by a total station, the root mean square (RMS) lateral error from the target path was 0.25 m in a no-wind day. The ultimate goal of the research is to realize autonomous herbicide application and paddy growth monitoring based on the USV platform.

1. Introduction

Rice is the most widely consumed staple food for a large part of the world's population. According to data published by the Japanese Ministry of Agriculture, Forestry and Fisheries, the area of paddy fields in Japan in 2014 was 24,580 km^2, which accounted for 54.4% of the total cultivated area. However, the number of farmers is declining year by year, and the aging of the farming population is a serious problem for Japan (Shimizu, 2012). Thus, the development of automated machines for paddy farming work has become an important issue.

Various farming tasks are carried out during the period of paddy growth, including cultivation of paddy seedlings, field tillage, paddy transplanting, spraying, weeding, fertilization and harvesting. Automation would be meaningful for all of these tasks. Many research achievements in paddy fields have been reported (Noguchi et al., 2002; Nagasaka et al., 2004; Chen et al., 2003; Kim et al., 2012; Choi et al., 2014). In addition, a surface vehicle is useful for moving on the surface of the water whether the water is shallow or deep. Based on the depth of water, an air propeller or an underwater propeller is used to producing propulsive momentum. Because of the flexible, low cost, and obvious low draft, various unmanned surface vehicles have been developed and used in many science and technology fields including geophysical exploration and environmental monitoring (Singh et al., 2008; Twichell et al., 2007; Kaizu et al., 2011).

Paddy plants are semi-aquatic plants. Their growth is strongly influenced by water supply. Water should be maintained in the field throughout the paddy growth period. Much water (100 mm in depth) is needed for paddy seedlings in the early stage of paddy growth (Brouwer et al., 1989). Various farming tasks including fertilizing and weeding are also conducted in this stage. However, because of the water, it is muddy in the paddy field. A wheel-type tractor or a crawler-type tractor cannot be used in a paddy field because the soil and paddy crops will be easily damaged by a tractor. So, now for fertilizing and weeding, manual work is still widely depended on. However, for large-scale intensive production, manual work is inefficient. Thus, there is a need to develop an unmanned surface vehicle platform that can be used in a paddy field before paddy transplanting and in the paddy early growth stage. Because of the low draft, an air propeller producing a column of air that produces propulsive momentum is normally used instead of an underwater propeller. Since a surface vehicle floats on the water, paddy seedlings will not be crushed. This is a lower cost, safer and faster way than using a ground vehicle such as a tractor or doing manual work.

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The main objective of this study was to develop an agricultural unmanned surface vehicle platform using a low-cost GPS compass for autonomous navigation in a paddy field. This agricultural USV platform should track the predefined target paths automatically. Based on this way, the USV can realize autonomous herbicide application and paddy growth monitoring using a machine vision.

2. Materials and methods

2.1. Hardware system

Considering the characteristics of paddy field, an underwater-propeller surface vehicle therefore cannot be used and an applicable surface vehicle body is necessary. In this study, a radio-controlled air propeller agricultural vessel (RB-26, Hokuto Yanmar) was modified as the main body of the USV. The draft of the surface vehicle is about 3 cm. Table 1 shows the specifications of the surface vehicle. The herbicide can flow out from the hole in the bottom of the agricultural vessel. The herbicide flow speed was controlled by one servo motor. It is hard to a farmer to control the vessel by a radio controller. Especially, the running vessel is far from the farmer's standing position, the farmer cannot recognize position and posture of the vessel. It is also hard to maneuver the vessel in a desired course. The operation accuracy will be very low. In order to implement the USV automation control, the engine throttle, which controlled the output power, was connected to a digital servo motor. Another digital servo motor was connected with the link lever to the fan of the air propeller. Controlling the servo motor can adjust the inclination angle of the fan to change the strength and direction (forward or backward) of the airflow from the air propeller. A single vertical rudder was positioned at the stern of the vehicle. The rudder can change the heading direction of the surface vehicle platform. Fig. 1 shows a scene of the USV platform operating in a paddy field in Shibetsu, Hokkaido, Japan.

For autonomous navigation and for observation on the embankment of the paddy field, the hardware system of the USV platform was divided into two parts, one part on the surface vehicle and one part on the embankment, as shown in Fig. 2.

On the surface vehicle, an onboard computer (DN2800MT, Intel), running the Windows 7 operation system, was mounted on the USV platform. The computer was used for navigation planning, communicating with other electronic devices and saving the running navigation state data. A dual multipath-resistant-antennas-based GPS compass (V100, Hemisphere GPS) was fixed on the top of the engine safety shield. The GPS compass system includes not only dual low-cost DGPS antennas but also a gyroscope, which can provide the sub-meter levels position and the heading angle of less than 0.50 RMS degrees accuracy. Positioning

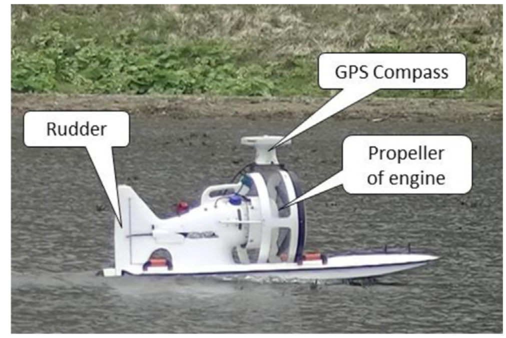

Fig. 1. Unmanned surface vehicle platform.

accuracy of the GPS compass is explained in details later. The GPS compass system was connected to the PC by a serial port to collect navigation data. In order to control the heading of the USV, an electronic control unit (ECU) based on an Arduino microcontroller board (UNO, Arduino) system was manufactured and used as the core of the underlying control and communication device. There were three digital servo motors to control the throttle of the engine, the fan's pitch lever of the air propeller and the rudder of the surface vehicle, respectively. The three digital servo motors were cooperatively controlled to change the running status of the USV platform. The rudder connected with digital servo motor using a metal linkage. For course change, the developed ECU can control the digital servo motor to change the rudder steering angle through the metal linkage. The maximum rudder angle is $\pm 40°$. A magnetic sensor (GV-101, FUTABA) was attached to the outside of the engine shell where the rotor was located to measure rotation speed of the engine. The magnetic sensor, as a feedback control device, was used for controlling the rotation speed via PID control. The PC calculated the navigation path planning, sent navigation command messages to the ECU to control the three servo motors renewing the running state of the USV platform, and uploaded the running state to the embankment of the paddy field by wireless network.

On the embankment of the paddy field, a laptop computer (X220, Lenovo) that received the wireless signals from the USV platform via a wireless router (WHR-HP-G300N, Buffalo) with a wireless local area network (WLAN) antenna (WTE-HG-NDC, Buffalo) was used to monitor the running state of the USV platform including speed, heading error, lateral error, and position on the predefined navigation map. All of these parameters were displayed and recorded in the navigation software interface. In addition, for operation variety, the manual operation was also retained. The original radio controller (T8J, FUTABA) with 8 signal channels is used to manually control the operation of the USV platform. In the

Table 1
Specifications of the surface vehicle.

Size	
Length	1850 (mm)
Width	780 (mm)
Height	680 (mm)
Weight	19 (Kg)
Power	
Engine type	ZENOAH G260PU (26 cc)
Max. power	1.62/12,000 (kw/rpm)
Max. torque	1.48/9000 (N·/rpm)
Idle rotation speed	1800 (APC18 × 8)
Fuel	Gasoline & Engine Oil
Fuel tank	1 (L)
Radio System	
Radio controller	FUTABA T8J
Radio receiver	FUTABA R604FS

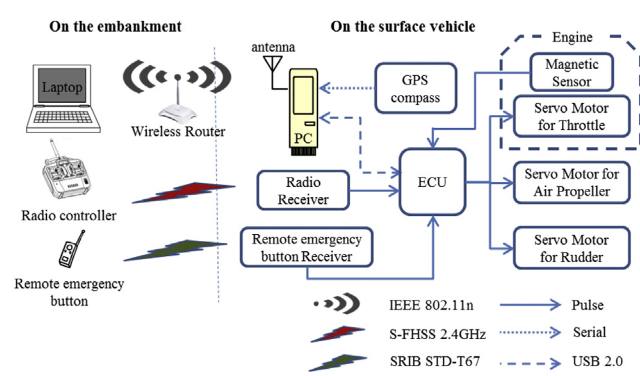

Fig. 2. Block diagram of the USV platform hardware.